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# Phenomenology of Charginos and Neutralinos in the Light Gaugino Scenario

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**Abstract:** The light gaugino scenario predicts that the lighter chargino mass is less than  $m_W$ , gluino and lightest neutralino masses are  $\lesssim 1$  GeV, and the dominant decay mode of charginos and non-LSP neutralinos is generically to three jets. The excess "4j" events observed by ALEPH in  $e^+e^-$  annihilation at 133 GeV may be evidence that  $m(\chi_1^\pm) = 53$  GeV. If so,  $m(\chi_2^\pm) = 110 - 121$  GeV,  $m(\chi_2^0) = 38 - 63$  GeV,  $m(\chi_3^0) = 75 - 68$  GeV;  $m(\tilde{\nu}_e)$  is probably  $\sim m(\chi_1^\pm)$ . A detailed analysis of the multi-jet events is needed to exclude this possibility. Consequences for FNAL and higher energy LEP running are given.

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In the light gaugino scenario the lighter chargino mass is  $\leq m_W$ . As we shall see, charginos and neutralinos generally decay to 3 jets, and squarks to two jets. The missing energy is too small in both cases to be a useful signature. The purpose of this paper is twofold: (i) to define the phenomenology of charginos and neutralinos in this scenario, and (ii) to investigate the possibility that the ALEPH excess “4 jet” events in 133 GeV  $e^+e^-$  annihilation come from decay of the lighter chargino.

Some supersymmetry (SUSY) breaking scenarios produce negligible tree-level gaugino masses and scalar trilinear couplings[1] ( $M_1 = M_2 = M_3 = A = 0$ ). As pointed out in refs. [2, 3], this has several attractive theoretical consequences such as the absence of the “SUSY CP problem” and avoidance of certain cosmological problems. Although massless at tree level, gauginos get calculable masses through radiative corrections from electroweak (gaugino/higgsino-Higgs/gauge boson) and top-stop loops. Evaluating these within the constrained parameter space leads to a gluino mass range  $m_{\tilde{g}} \sim \frac{1}{10} - \frac{1}{2}$  GeV and photino mass range  $m_{\tilde{\gamma}} \sim \frac{1}{10} - 1\frac{1}{2}$  GeV[2, 3]. The chargino and other neutralino masses are functions only of  $\mu$  and  $\tan\beta$ . In particular,

$$2M_{\chi^\pm}^2 = \mu^2 + 2m_W^2 \pm \sqrt{\mu^4 + 4m_W^4 \cos^2 2\beta + 4m_W^2 \mu^2}, \quad (1)$$

so one chargino is lighter, and the other heavier, than  $m_W$ . The photino is an attractive dark matter candidate, with a correct abundance for parameters in the predicted ranges[4].

Due to the non-negligible mass of the photino compared to the lightest gluino-containing hadron, prompt photinos[5] are not a useful signature for the light gluinos and the energy they carry[6]. Gluino masses less than about  $\frac{1}{2}$  GeV are largely unconstrained[7]<sup>2</sup>, although such light gluinos would cause modifications in jet distributions[10, 11, 12] and have other indirect effects,

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<sup>2</sup>The recent claim[8] that LEP  $Z^0 \rightarrow 4j$  data can be used to exclude light gluinos is premature. Although the statistical power of the data is sufficient, the relevant angular distributions are particularly sensitive to higher order effects such as 5-jet production. This is evidenced by the spread of predictions in the absence of light gluinos shown in Fig.

e.g., on the running of  $\alpha_s$ [13, 14]. The lifetime of the gluon-gluino bound state ( $R^0$ ) is predicted to be  $10^{-5} - 10^{-10}$  sec[3]. Proposals for direct searches for hadrons containing gluinos, via their decays in  $K^0$  beams and otherwise, are given in Ref. [15].

For the purposes of detecting squarks and charginos, the crucial phenomenological difference arising when the gluino is light rather than heavy as is usually assumed, is that the gluino is long-lived. Therefore it makes a jet rather than missing energy[6]. Squarks decay to gluino and quark, thus generating two jets with negligible missing energy<sup>3</sup>. QCD background makes it impossible, with present jet resolution, to search at hadron colliders in the dijet channel for masses lower than about 200 GeV; a search for equal-mass dijet pairs as suggested in [16] has not yet been completed. At present, the best squark mass limits come from the hadronic width of the  $Z^0$  and are only  $\sim 50 - 60$  GeV[17, 18].

The rate for a two-body decay of a chargino to an SU(2) doublet can be written

$$\Gamma(\chi^\pm \rightarrow \tilde{D} + U) = N_c \cos^2 \phi \frac{\alpha_2 |k|}{8 M_{\chi^\pm}^2} (M_{\chi^\pm}^2 + m_q^2 - M_{\tilde{q}}^2), \quad (2)$$

where  $N_c$  is the QCD multiplicity of the fermion (3 for quarks, 1 for leptons),  $|k|$  is the CM momentum of the final state particles, and  $\cos \phi$  is the effective amplitude that the chargino is a  $\tilde{w}^\pm$ .<sup>4</sup> For  $\mu$ ,  $\tan \beta$  values in the relevant range (see below), charginos are an approximately equal admixture of wino and higgsino. Thus  $\chi_i^\pm \rightarrow \tilde{t}_R + \tilde{b}_L$  is an important decay mode, if kinematically allowed.

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<sup>5</sup>of ref. [9], which is an order of magnitude larger than the effect due to light gluinos (see Fig. 2 of ref. [10]). Therefore as stressed in [10], no conclusion can be drawn until the NLO calculation of the  $Z^0 \rightarrow 4j$  matrix element is available.

<sup>3</sup>The missing energy associated with the ultimate decay of the lightest  $R$ -hadron to a photino is far below  $E_{miss}$  cuts in squark searches[16].

<sup>4</sup>Here,  $\cos \phi = U_{i1}$  in the notation of [19]; for  $\Gamma(\chi_i^\pm \rightarrow \tilde{U} + \tilde{D})$ ,  $\cos \phi = V_{i1}$ . In eq. (3),  $\cos \bar{\phi} \equiv (U_{i1} + V_{i1})/2$ .

The total rate for hadronic three-body decays is proportional to the decay rate calculated long ago for the gluino[20], so modifying the overall factor appropriately:

$$\Gamma(\chi^+ \rightarrow \tilde{g} + \bar{D} + U) = \frac{\alpha_s \alpha_2 \cos^2 \bar{\phi}}{16\pi} \frac{M_{\chi^\pm}^5}{M_{\tilde{q}}^4}, \quad (3)$$

where for brevity squark masses have been taken equal and quark and gluino masses neglected.

The most important feature to note is that if the gluino is light and  $M_{\tilde{q}}$  is not  $\gg m_W$ , the overwhelmingly dominant three-body final state is  $q\bar{q}'\tilde{g}$ , produced by a virtual squark<sup>5</sup>. Thus unless two-body decays are possible, or sneutrinos or sleptons are much lighter than squarks, or sfermions are much heavier than  $W$ 's, the lighter chargino and the three heavier neutralinos will almost always decay to three jets with no missing energy. Since  $M(\chi_2^\pm) \geq m_W$ , the two-body decay  $\chi_2^\pm \rightarrow W^\pm + \tilde{\gamma}$  is allowed and will be an important decay mode, except very near  $M(\chi_2^\pm) = m_W$ . Another possible exception to the dominance of  $q\bar{q}\tilde{g}$  final states occurs when  $\tan\beta$  is close to one: in this case,  $\chi_3^0$  has very little  $\tilde{z}$  component and its dominant decay mode may be through a stop-top loop to  $\gamma\tilde{\gamma}$ .

If  $M_{\tilde{q}} \sim M_{\chi^\pm}$ , the matrix element favors one jet being much softer than the other two. This is easy to see for the two-body decay  $\chi^\pm \rightarrow \tilde{q} + q'$  with  $M_{\chi^\pm} \gg M_{\chi^\pm} - M_{\tilde{q}} > 0$ , for which the primary jet ( $q'$ ) has energy  $\approx M_{\chi^\pm} - M_{\tilde{q}}$  in the  $\chi^\pm$  rest frame, while the quark and gluino from the squark decay each have  $E \approx M_{\tilde{q}}/2$ . If one jet is much softer than the other two, particles from that jet will often be merged into the hard jets by the jet finding algorithm and a chargino will give rise to “2j”, i.e., a multijet system designated as two jets. With a sample of candidate chargino events,

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<sup>5</sup>For  $M_{\tilde{q}} \sim m_W$ , it is a factor  $\frac{2 \cdot 8 \alpha_3}{(2 \cdot 3 + 3) \alpha_2} \sim 5$  larger than virtual  $W$  decay, summing over the two generations of light quarks and three generations of leptons, and a factor  $8 \frac{\alpha_3}{\alpha_2} \sim 25$  larger than virtual slepton or sneutrino decay. The former gives  $\chi^0 q\bar{q}'$  two-thirds of the time and otherwise  $\chi^0 l\nu$ , while the latter gives  $l\nu\chi^0$ .

analysis of the relative number of events with resolved jets can give limits on the intermediate squark mass:  $M_{\tilde{q}} \gg M_{\chi^\pm}$  leads to final states with jets of comparable energy, while  $M_{\tilde{q}} \sim M_{\chi^\pm}$  leads to states in which one jet has much lower energy than the other two and thus is less easily resolved.

In the LEP 133 GeV run, ALEPH observed 16 “ $4j$ ” events when 8.6 were expected [21]. The excess was localized in the total-dijet-mass range 102-108 GeV, where 9 events were observed when 0.8 was expected. Moreover most of the events in this peak region are not characteristic of the SM expectation with regard to their angular distribution and dijet charge-difference. This reduces the likelihood that the events were simply a statistical fluctuation of a standard model process.

Assuming this excess is due to pair production of equal mass particles which decay to two jets<sup>6</sup> implies a cross section of  $3.1 \pm 1.7$  pb. Taking the 4 LEP experiments together gives a cross section of  $1.2 \pm 0.4$  pb<sup>7</sup>. With this cross section it is not particularly improbable that one of the 4 experiments should get 16 events (SM model expectation 8.6) out of the total of 49 events observed, and the others together have 33 (with 26.4 expected in the SM). Furthermore in the 102-108 GeV total-dijet-mass region the other experiments also observed an excess: 6 events when 2.6 were expected.

Pair production of  $\sim 53$  GeV charginos could give rise to “ $4j$ ” events with total dijet mass of 105 GeV at the observed rate. The ALEPH jet-reconstruction algorithm explicitly merged  $5j$  to  $4j$ , and ignored the small number of clear  $6j$  events. An important point is that due to the experimental imprecision in energy measurements, LEP experiments rescale the momenta and energies of jets to enforce overall energy momentum conservation. The directions of the jets are assumed to be accurately measured, and the jets

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<sup>6</sup>E.g.,  $h A$ , although that is unlikely to be the origin of the excess events, since its cross section is 0.49 pb for  $M(h) = M(A) = 53$  GeV and there is no observed excess of  $b\bar{b}$ 's in the events.

<sup>7</sup>Results from the ensemble of LEP experiments are taken from P. Mattig, XXVIII Intl. Conf. for High Energy Physics, Warsaw, July 24-31, 1996.

taken to be massless. Then, since energy-momentum conservation provides 4 equations, up to 4 jets can be independently rescaled. However if the event actually contains 6 jets and the invariant mass of merged pairs of jets is non-negligible, the procedure of rescaling the magnitudes of the momenta of the 4 jets distorts the invariant masses of the "dijets". Detailed Monte Carlo study is needed to assess the extent to which this causes the chargino or neutralino invariant mass peaks to be lost, and the beam energy dependence of this effect.

The chargino production cross section depends on  $\mu$ ,  $\tan\beta$  and  $M_{\tilde{\nu}_e}$ .  $M_{\chi_1^\pm} = 53$  GeV requires a relation between  $\mu$  and  $\tan\beta$ , eq. (1), which also ensures that the chargino is an approximately equal mixture of higgsino and wino. Therefore the main uncertainty in cross section is due to its sensitivity to the electron sneutrino's mass,  $M_{\tilde{\nu}_e}$ . Imposing  $M_{\chi_2^0} \geq 38$  GeV (see below), causes  $[\mu, \tan\beta]$  to range between  $[45, 1.6]$  and  $[70, 1]$ <sup>8</sup>. For instance for  $M_{\tilde{\nu}_e} = 60$  GeV,  $\tan\beta = 1.4$  and  $\mu = 56$  GeV, one finds  $\sigma(\chi^+\chi^-) = 3.6$  pb at  $E = 133$  GeV, and 2.1 (1.9) pb at  $E = 161$  (190) GeV. The smallest possible  $\chi_1^+\chi_1^-$  cross section at 133 GeV is 2.4 pb, for  $M_{\tilde{\nu}_e} = 50$  GeV, while the largest possible cross section is 14 pb (for  $M_{\tilde{\nu}_e} \gg M_{\chi_1^\pm}$ ,  $\tan\beta = 1$  and  $\mu = 68.4$  GeV).

If at 133 GeV most  $\chi_1^\pm \rightarrow q\bar{q}\tilde{g}$  decays are captured by the ALEPH analysis procedure, a cross section to "4j" as low as 1.2 pb suggests a competing decay mode. This could be  $\chi_1^\pm \rightarrow l\tilde{\nu}$ , with the  $\tilde{\nu}$  decaying to lsp and neutrino and thus going undetected. The branching fraction for  $\chi_1^\pm \rightarrow l\tilde{\nu}$  is a very sensitive function of the sneutrino mass and also depends on the squark mass and the number of light sneutrinos. The mass splitting must be less than about 0.5 GeV in order not to excessively reduce the branching fraction to

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<sup>8</sup>We take  $\tan\beta \geq 1$  without loss of generality because in the absence of tree-level gaugino masses and scalar trilinear couplings, the chargino and neutralino spectrum is unchanged by  $\tan\beta \rightarrow 1/(\tan\beta)$ ; only the roles of the higgsinos,  $h_U$  and  $h_D$ , are interchanged in the eigenstates.

the hadronic channel. With such a small splitting, the lepton energy is too low for events with two leptonic decays to be accepted. Since the detection efficiency for leptons drops very rapidly with momentum, events with one chargino decaying hadronically to  $q\bar{q}\tilde{g}$  and the other to lepton and missing energy may be difficult to detect. The LEP experiments should explore what limits can be placed on this possibility.

We can hope that higher integrated luminosity will allow the 53 GeV chargino hypothesis to be promptly confirmed or excluded. With greater CM energy the jet systems from each chargino decay will be better collimated and more readily separated from one another, so the angular distribution of the jet systems can be more cleanly determined than at lower energy. It should  $\sim 1 + \cos^2\theta$  because charginos are spin-1/2. On the other hand, Monte Carlo simulations<sup>9</sup> show that the resolution in dijet mass difference does not improve significantly with energy even for genuine two-body decays of pair-produced particles, due to reduced effectiveness of the energy-momentum constraint at higher energy. This will probably be an even more severe problem for the 6j case at hand. It is ironic that  $W^+W^-$  production will be a non-trivial background at 161 GeV and above, since they decay with rather high probability to  $> 2j$  (40 % of  $Z^0$  decays contain  $\geq 3j$ , with  $y_{cut} = 0.01$ ) and their cross section is about a factor of 5 larger than that of charginos, whose cross section at 161 GeV, extrapolating from 1.2 pb at 133 GeV, is 0.8 pb. As of the Warsaw conference, with each experiment having about 3.2 pb<sup>-1</sup> integrated luminosity at 161 GeV, no excess of events was observed. This gives a 95% cl upper limit of 0.85 pb on the production of 4j events. However the efficiency of seeing 6j events with the 4j analysis is presently unknown, so this limit cannot be directly applied to  $\chi^+\chi^-$  production.

What else can be said about the SUSY spectrum under the 53 GeV chargino hypothesis? First of all, if a sneutrino (selectron) were light enough

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<sup>9</sup>M. Schmitt, private communication.

that the two-body decay  $\chi^\pm \rightarrow \tilde{\nu} + l$  or  $\chi^\pm \rightarrow \tilde{l} + \nu$  (branching fraction  $b_l$ , taken together) could compete with the hadronic decays (branching fraction  $b_h$ ), one should see other signatures. Events with two leptons and missing energy should occur at a rate  $(b_l/b_h)^2$  compared to the “4j” events, and there should be mixed final states with “2j”, a single lepton, and missing energy at a relative rate  $2b_l/b_h$ . The charged lepton will be soft or hard, depending on which decay ( $\chi^\pm \rightarrow \tilde{\nu} + l$  or  $\chi^\pm \rightarrow \tilde{l} + \nu$ ) dominates. These final states would have shown up in LEP SUSY searches unless the charged lepton is extremely soft, so we can conclude that  $m(\tilde{l}) > 53$  GeV and  $m(\tilde{\nu}) \gtrsim 50$  GeV<sup>10</sup>.

We can also deduce that the right-stop is probably heavier than the chargino. A stop lighter than the top would decay through FCNC mixing, to a gluino and presumably charm quark<sup>11</sup>. If the decay  $\chi_1^\pm \rightarrow \tilde{t}_1 + b$  were allowed, each event would contain soft  $b\bar{b}$  and hard  $c\bar{c}$  jets in addition to the gluino jets. However even if  $\chi_1^\pm \rightarrow \tilde{t}_1 + b$  is not allowed, when chargino decay is mediated by a real or virtual stop we would expect two hard charm-quark jets in each chargino event. ALEPH has searched for  $b$ ,  $\bar{b}$ ,  $c$ , and  $\bar{c}$  jets in their 4j sample. They found only a single event consistent with a displaced vertex or excess lepton activity from the  $e$  or  $\mu$  produced in 20% of the  $c$  and  $b$  decays, and no evidence for an excess in comparison to QCD expectations[21]. So we conclude that  $M_{\tilde{t}_1}$  is probably  $\gtrsim 53$  GeV<sup>12</sup>.

Now let us turn to the neutralinos and heavier chargino. In the tree-level massless gaugino scenario, the lightest neutralino gets its mass through radiative corrections[23, 24] and has mass  $\lesssim 1\frac{1}{2}$  GeV[2, 3]. It is practically pure photino. The masses of the others are determined by  $\mu$  and  $\tan\beta$ , since tree-level gaugino masses vanish. Since  $\chi_1^0\chi_1^0$  and  $\chi_1^0\chi_2^0$  production is

<sup>10</sup>The 3 GeV mass difference required to see the soft leptons is evident in Fig. 7 of [22].

<sup>11</sup>Information on FCNC mixing involving the third generation is poor, so mixing between third and first generations may also occur.

<sup>12</sup>Chargino decay through virtual stops may be highly suppressed by the FCNC factor, which is irrelevant for on-shell stops, so for  $M_{\tilde{t}_1} \gtrsim 53$  GeV we cannot use such reasoning to decide how  $M_{\tilde{t}}$  compares to the other squark masses.

severely suppressed by the absence of a higgsino component in  $\chi_1^0$ , the only constraints of importance come from  $\chi_2^0\chi_2^0$  production. Fixing the relation between  $\mu$  and  $\tan\beta$  so  $M(\chi_1^\pm) = 53$  GeV, implies  $M(\chi_2^0) \geq 45$  GeV if  $\mu \geq 50$  GeV. In this case  $\chi_2^0$  could not be pair-produced in  $Z^0$  decays. A somewhat lower mass  $\chi_2^0$  is actually not excluded, since  $\chi_2^0$  decays practically exclusively to  $3j$  final states and therefore would not have been detected in existing neutralino searches. Allowing  $M(\chi_2^0) = 38$  GeV (i.e.,  $\mu = 45$  GeV,  $\tan\beta = 1.6$ ) would result in an increment of about 10 MeV in the hadronic width of the  $Z^0$ , whose PDG value is  $\Gamma_{had}(Z^0) = 1741 \pm 6$  MeV. For reference, the SM prediction for  $\Gamma_{had}(Z^0)$  would drop by about this amount if  $\alpha_s(M_Z)$  were in fact 0.115 as suggested by low energy data<sup>13</sup>. For  $M_{\chi_2^0} = 38$  GeV,  $\chi_2^0$  has a large  $\tilde{h}_D$  component ( $\chi_2^\pm = -0.86\tilde{h}_D - 0.39\tilde{h}_U + 0.31\tilde{z}^0$ ). This leads to an excess in the  $b\bar{b}\tilde{g}$  final state in  $\chi_2^0$  decay, but not enough to affect  $R_b$  significantly.

Having restricted the range of  $[\mu, \tan\beta]$  to  $[45, 1.6] - [70, 1]$ , we find the heavier *ino* mass ranges:  $M(\chi_3^0) = 76 - 68$  GeV,  $M(\chi_4^0) = 118 - 132$  GeV and  $M(\chi_2^\pm) = 110 - 120$  GeV. See Fig. 1.

At 133 GeV,  $\sigma(e^+e^- \rightarrow \chi_2^0\chi_2^0) < 0.5$  pb for typical parameter choices, although for  $M(\chi_2^0) \lesssim 45$  GeV the cross section (including enhancement from initial state radiation) is  $\gtrsim 1$  pb. Thus a small number of events might be present in the 133 GeV multi-jet sample for each experiment. Such events should exhibit  $\Delta Q$  consistent with zero. Production of  $\chi_2^0\chi_3^0$  is at least an order of magnitude lower.

A  $p\bar{p}$  collider is sensitive to both  $\chi_i^0\chi_j^\pm$  production via  $W^*$ , and  $\chi_i^0\chi_j^0$  or  $\chi_i^\pm\chi_i^\pm$  production via  $\gamma^*$  and  $Z^*$ . The former has the largest cross section so is of greatest interest. A small excess production of  $6j$  events is not a promising signature at a hadron collider so it is fortunate that there are two possible exceptions to the hadronic decay of *inos*.

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<sup>13</sup>In the light gluino scenario, however, evolution from  $\alpha_s = 0.11$  at 10 GeV leads to  $\alpha_s(M_{Z^0}) = 0.122$ , in agreement with the quoted LEP average of 0.125.

1. If  $\tan\beta$  is near 1, i.e.,  $\mu \approx 70$  GeV,  $\chi_3^0$  has practically no gaugino component and is essentially a symmetric  $\tilde{h}_U + \tilde{h}_D$  state. Therefore for some range of parameters,  $\chi_3^0 \rightarrow \gamma\chi_1^0$  competes with the hadronic decay  $\chi_3^0 \rightarrow b\bar{b}\tilde{g}$ . In this range,  $\chi_3^0\chi_{1,2}^\pm$  gives events with a single  $\gamma$ , large missing energy, and 3 jets (the decay products of  $\chi_1^\pm$  or  $\chi_2^\pm$ ). If  $\chi_2^\pm \rightarrow \tilde{t}_1 + b$  is kinematically possible,  $\chi_2^\pm\chi_3^0$  production will give events with a single  $\gamma$ , missing energy, and  $b + c + \tilde{g}$  jets reconstructing to the heavier chargino mass, which is predicted to lie in the range 110-120 GeV.
2. If all squarks are more massive than  $\chi_2^\pm$ , then  $\chi_2^\pm \rightarrow W^\pm\tilde{\gamma}$  will compete with its 3-body hadronic decay. In this case  $\chi_2^\pm\chi_{2,3,4}^0$  production would give events with  $W$ ,  $E_{miss}$  and 3-jets (or  $W, \gamma$  and  $E_{miss}$  if  $\chi_3^0 \rightarrow \gamma\tilde{\gamma}$ ).  $\chi_2^\pm\chi_2^\pm$  would give events with  $W^+W^-$  and  $E_{miss}$ .

The CDF  $e^+e^-\gamma\gamma+E_{miss}$  event[25] could in principle arise in this scenario, through  $\tilde{e}\tilde{e}$  production, with  $\tilde{e} \rightarrow e\chi_3^0$  followed by  $\chi_3^0 \rightarrow \gamma\tilde{\gamma}$ . However a lone  $ee\gamma\gamma$  would be very improbable, since the large higgsino component needed to make  $\chi_3^0 \rightarrow \gamma\tilde{\gamma}$  a dominant decay channel reduces its relative production rate in selectron decay.

To summarize:

- The generic final state for neutralinos and charginos in the light gaugino scenario is three jets, unless  $m(\tilde{\nu})$  is small enough that two-body leptonic decays are allowed.
- Chargino production and decay gives a good description of the rate and characteristics of “4j” events seen by ALEPH at 133 GeV, in the light gaugino scenario (with no R-parity violation), for chargino mass of  $\approx 53$  GeV.
- If this is the origin of the anomalous events, the chargino is probably

lighter than any squark, but has a mass comparable to the electron sneutrino.

- Independent of the chargino interpretation of the ALEPH  $4j$  events at 133 GeV, neutralino masses are  $m(\chi_1^0) \sim 1$  GeV and  $m(\chi_2^0) \gtrsim 38$  GeV in this scenario.
- If the ALEPH hint of charginos at 53 GeV disappears with more statistics, the prospects for finding charginos in the light gaugino scenario are still good. At  $E=190$  GeV the cross section for chargino pair production is greater than 1.4 pb for  $M_{\tilde{\nu}_e} = 100$  GeV, even for the most pessimistic case of degenerate charginos with mass  $m_W$ ; for large  $M_{\tilde{\nu}_e}$  the cross section is greater than 4 pb. The  $6j$  signal may be difficult to discriminate from the background, however.

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## References

- [1] T. Banks, D. Kaplan, and A. Nelson. *Phys. Rev.*, D49:779, 1994.
- [2] G. R. Farrar. Technical Report RU-95-17 and hep-ph/9504295, Rutgers Univ., April, 1995.
- [3] G. R. Farrar. Technical Report RU-95-25 and hep-ph/9508291, Rutgers Univ., 1995.
- [4] G. R. Farrar and E. W. Kolb. *Phys. Rev.*, D53:2990, 1996.
- [5] G. R. Farrar and P. Fayet. *Phys. Lett.*, 79B:442–446, 1978.

- [6] G. R. Farrar. *Phys. Rev. Lett.*, 53:1029–1033, 1984.
- [7] G. R. Farrar. *Phys. Rev.*, D51:3904, 1995.
- [8] A. de Gouvea and H. Murayama. Technical Report LBL-39030 (hep-ph/9606449), LBL/UCBerkeley, 1996.
- [9] The Opal Collaboration. *Zeit. fur Phys.*, 49:49, 1991.
- [10] G. R. Farrar. *Phys. Lett.*, 265B:395, 1991.
- [11] L. Clavelli and I. Terekhov. Technical Report UAHEP966 (hep-ph/9605463), U. Alabama, 1996.
- [12] Z. Bern, A. Grant, and A. Morgan. Technical Report UCLA/96/TEP/21 (hep-ph/9606466), U. Alabama, 1996.
- [13] G. R. Farrar. *Proceedings of the Cornell Z' Theory Workshop, Feb. 6-8, 1981.*
- [14] M. Jezabek and J. Kuhn. *Phys. Lett.*, B301:121, 1993.
- [15] G. R. Farrar. *Phys. Rev. Lett.*, 76:4111, 1996.
- [16] G. R. Farrar. *Phys. Rev. Lett.*, 76:4115, 1996.
- [17] L. Clavelli et al. *Phys. Lett.*, B291:426, 1992.
- [18] G. Bhattacharyya and A. Raychaudhuri. *Phys. Rev.*, D49:1156, 1994.
- [19] J. Gunion and H. Haber. *Phys. Rev.*, D37:2515, 1988.
- [20] H. Haber and G. Kane. *Nucl. Phys.*, 232B:333, 1984.
- [21] The Aleph Collaboration. Technical Report PPE/96-052, CERN, 1996.
- [22] The Aleph Collaboration. Technical Report PPE/96-083, CERN, 1996.

- [23] G. R. Farrar and A. Masiero. Technical Report RU-94-38, hep-ph/9410401, Rutgers Univ., 1994.
- [24] D. Pierce and A. Papadopoulos. *Nucl. Phys.*, B430:278, 1994.
- [25] S. Park for the CDF Collaboration. In *10th Topical Workshop on ppbar Collider Physics*. AIP, 1996.

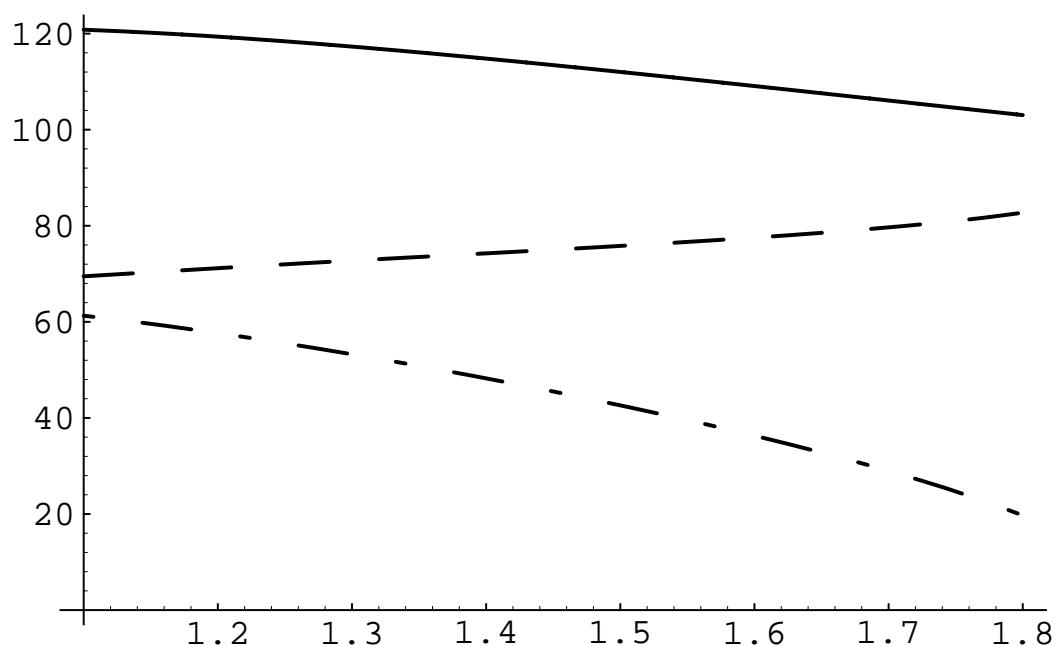


Figure 1: Masses in GeV of the heavier chargino and second and third neutralinos as a function of  $\tan\beta$ , fixing the lighter chargino mass to 53 GeV (solid, dash-dot, and dash curves, respectively).